DAFOSYM

A Tool for Evaluating Alternative Dairy Systems

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Content

Introduction

Many alternative technologies and management strategies are available to today's dairy farmer. These include choices in the number and type of animals, land area, crop mix, equipment, feed storage facilities, animal facilities, manure handling options, and much more. Changes in one component of the farm often affect other components, and this interaction can cause changes in the performance or profitability of the farm that are not obvious. Many options are currently available and new alternatives are introduced each year.

Quantifying and comparing the benefits and costs of alternative technology in farming is not easy. A technology that performs well under one set of crop and weather conditions may not perform well at other times. Long term studies are needed to quantify the benefits and costs over a wide range of conditions. Field studies of this type are costly, impractical, and perhaps impossible. Another approach is to use computer simulation. Models developed and validated with limited field experimental work can be used to study system performance over many years of weather.

DAFOSYM (The Dairy Forage System Model) is a simulation model developed specifically for the dairy farm. DAFOSYM was primarily developed as a research tool for evaluating alternative technology, but it also provides an effective teaching aid. With the model, students gain a better appreciation for the complexity of dairy forage systems. They learn how small changes affect many

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parts of the system causing unanticipated results. They may also use the model to develop a more optimum food production system. When used in extension-type teaching, producers can learn more about their farms and obtain information useful in strategic planning.

History of DAFOSYM

The US Dairy Forage Research Center (USDFRC) has been involved in the modeling of the dairy forage system since the beginning of the Center in the late seventies. A portion of the first funding of the Center was provided to Michigan State University to begin the development of a simulation model of dairy forage production. A model was created through the cooperative effort of two graduate students and several university faculty (Savoie et al. 1985). The model became known as DAFOSYM. It was written in FORTRAN for use on a mainframe computer. This version of the model was relatively crude, but it provided a suitable structure for further development. After the East Lansing Cluster program was staffed in 1981, the USDFRC continued the development of the model. During the next few years, most of the modeling effort was given to refining the relationships used to describe field curing and harvest losses (Rotz 1985).

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In 1985, the model was converted to function on personal computers. Development continued toward making the model more convenient to use and more adaptable to other technology and locations. In the late eighties, a major effort was undertaken to upgrade the storage and animal submodels of DAFOSYM. With the help of others in the USDFRC and cooperators in the NE 132 Regional Research Project, submodels of hay storage, silo storage, and the animal were completed (Buckmaster et al. 1989a, 1989b; Rotz et al. 1989). For the next five years, the emphasis of the modeling effort was directed toward application of the model to evaluate systems. Evaluations of the benefits and costs of various technology for forage conditioning, maceration and mat drying, swath manipulation, hay drying, and preservation were analyzed with the model. The model was also used for management decisions such as machine and silo selection and sizing.

In 1991, the user interface was upgraded to allow the model to be used as a teaching aid. This DOS version of the model used overlaying menus for editing model parameters and a plotting package for high quality graphical output. Over 300 copies of this package were distributed, primarily to extension and teaching faculty in the U.S. and Canada with several copies going to other countries. Development of the model continued as submodels for manure handling, tillage, and planting were added.

During the past two years, DAFOSYM was converted to a Windows® operating system. A new user interface was developed to provide a more user oriented model. The conversion also allowed further expansion of the model. The model was expanded to include animal facilities and essentially all costs incurred on typical dairy farms making it a more complete dairy farm model. Grazing of forage and a wide variety of possible feed supplements were also added. Work is now underway to incorporate additional crop options. This expanded model will be used to study the effects of crop rotation and feed supplementation on farm performance, profit, and nutrient loss to the environment.

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Model Description

DAFOSYM is a simulation model of crop production and feed use on dairy farms and the return of manure nutrients back to the land (Fig.1). This dairy forage system is simulated over many years of weather to determine the long term performance and economics of alternative technologies and/or management strategies (Rotz et al. 1989; Borton et al. 1995). By modeling several alternatives on the same representative farms, those alternatives that provide maximum farm production or profit are determined.

Farms are simulated over historical weather conditions. An alfalfa growth routine predicts daily yield and nutrient content throughout the growing season. When ready for harvest, a harvest routine simulates field machinery opera-

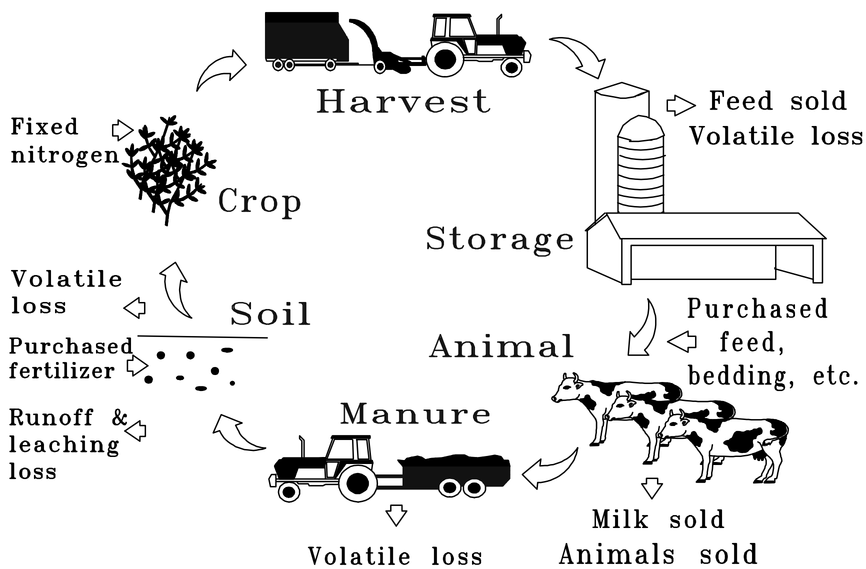

Figure 1. DAFOSYM simulates material and nutrient flows for various dairy farm systems over many years of weather and determines the economics of the farm.

"An economic analysis is performed for each year based upon farm performance."

tions, drying, and rewetting in three-hour increments. Losses and nutritive changes due to machine operations, plant respiration, and rain damage are accounted to predict the quantity and quality of forage harvested. A corn model predicts corn grain and silage yields, and a harvest routine accounts for losses and resource requirements during harvest. Storage losses and associated nutritive changes are predicted for dry hay, silage, and grain stored by different methods. Following storage, balanced diets are fed to each of six animal groups with higher quality forage fed to high producing animals. Supplemental feeds are purchased to meet protein and energy requirements of the herd, and extra feeds are sold.

Manure production is modeled as feed dry matter (DM) consumed minus the digestible DM extracted by the animals plus urine DM and any feed DM lost into the manure. The quantity of wet manure handled is influenced by the type and amount of bedding and the manure moisture content. Nutrients in fresh manure are determined through a mass balance of the six animal groups. Manure nutrients equal the nutrient intake minus nutrients contained in milk produced and in animal tissue acquired through growth. Nutrients excreted minus losses give the nutrients available for plant growth. Nitrogen losses during collection, storage, and application are modeled as functions of temperature, storage method, and the time between spreading and incorporation.

Crop nutrient requirements are based on the nutrients removed in the harvested crops. These requirements are met with purchased fertilizer minus credits from crop rotation carryover and manure. When land is rotated from alfalfa into corn, the nitrogen requirement is reduced to credit soil nitrogen remaining from the previous crop. Manure is applied to each crop until the most limiting nutrient is met allowing only a small over-application of the nutrient. Manure is first applied to corn silage land, then to corn grain land, and next to new alfalfa land with any remainder spread on established alfalfa stands.

From one to six operations can be used for tillage and planting of each crop. On any given parcel of land, the operations must occur in a sequence, but more than one operation can occur simultaneously. Soil moisture on the field surface is tracked through time to predict days suitable for field work. The moisture is increased by rainfall and decreased through evapotranspiration and moisture flow to lower soil layers. Field operations are allowed only on days when the moisture is below a critical level. Tillage follows manure handling in the sequence of spring and fall operations. A delay in planting due to untimely operations results in a decrease in corn yield.

An economic analysis is performed for each year based upon farm performance. All costs associated with growing, harvesting, storing, and feeding of crops, milking and care of the animals, and the collection, storage, and application of manure back to the crop land are accounted. Production costs include annual costs of capital investments in machinery and structures and annual operating costs. Operating costs include labor, fuel and electricity, maintenance and repair of machinery, land, seed, fertilizer, chemicals, and supplemental feeds. A net return over feed and manure costs is determined as the difference between the income from milk sales and the net cost of feeding the animals and handling the manure. Additional costs for animal housing, milking, herd health, *"The primary goal in the development of DAFOSYM was a research tool for evaluating options for the dairy farm."*

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and herd maintenance are next included to estimate the total production cost and the net return or profit of the whole farm.

All production costs and the net return over those costs are determined for each simulated year of weather. The distribution of annual values obtained can then be used to assess the risk involved in alternative technologies or strategies as weather conditions vary. A wide distribution in annual values implies a greater degree of risk for a particular alternative. The selection among alternatives can be made based upon the average annual net return or the probability of attaining a desired net return.

A Research Tool

The primary goal in the development of DAFOSYM was a research tool for evaluating options for the dairy farm. A wide range of technologies were compared with the model and the results are published in journals and conference proceedings. Several examples follow.

Hay Drying

Chemical conditioning of alfalfa was introduced in the late seventies. Field experiments conducted to develop a practical system for hay producers provided equipment parameters and data required to develop and validate field-curing submodels for DAFOSYM (Rotz 1985). Simulations of the process on representative farms in the Eastern and Midwestern US indicate that the process can reduce field curing time an average of about 12 h on first cutting and 24 h on later cuttings. This results in more high quality hay which reduces feed costs on the dairy farm. With a treatment cost near $5/t dry matter of hay, the technique returns the cost of the treatment through improved hay quality, and may provide a small economic gain for the producer. Many producers have tried this process, but only a few continue to use it due to the marginal economic benefit and the inconvenience of handling the chemical.

Mat drying of hay is a new technology under development at the USDFRC and elsewhere in the US, Canada, and Europe. Forage is shredded and pressed into a mat that is laid back on the field for rapid drying. The matted forage dries to baling moisture in about one day with minimal loss even in humid climates. Shredding also improves the digestibility of the forage. Experimental work quantified the drying rates, losses, and machinery requirements for the process. DAFOSYM simulations show that the new technology can be quite economical (Rotz et al. 1990). The proposed equipment is costly, but the model predicts that in the Midwest the process may return up to $4 for each dollar spent on increased equipment costs through improved hay quality.

Hay storage

Chemical and biological agents are often used to preserve high-moisture hay. By baling damp hay, field losses are reduced, but storage losses are increased. Hypothetical treatments with a wide range of effectiveness in preserving high-moisture hay were simulated for several strategies of use to determine potential break-even treatment costs. Actual treatment costs are considerably greater than the break-even costs determined through simulation which indicates an economic loss with current treatments (Rotz et al. 1992). Simulation results provide preservative manufacturers with guidelines on effectiveness versus cost for future product development.

Large round hay bales can be stored using a variety of methods. The long term performance, costs, and return above feed costs for six storage methods, three bale sizes, two feeding methods, and two milk production levels were compared on 60 and 400 cow dairy farms (Harrigan et al. 1994). The value of bale protection was influenced by bale size, amount of hay in the diet, level of milk production, and feeding method. Shed storage was usually, but not always, more profitable than unprotected storage. The greatest economic return from bale protection occurred when small diameter bales were fed to high producing cows with all alfalfa fed as dry hay. Compared to unprotected hay, annual net return increased as much as $155/cow with shed storage and $143/cow with tarp-covered stacks. The least benefit from bale protection was when large diameter bales were chopped and

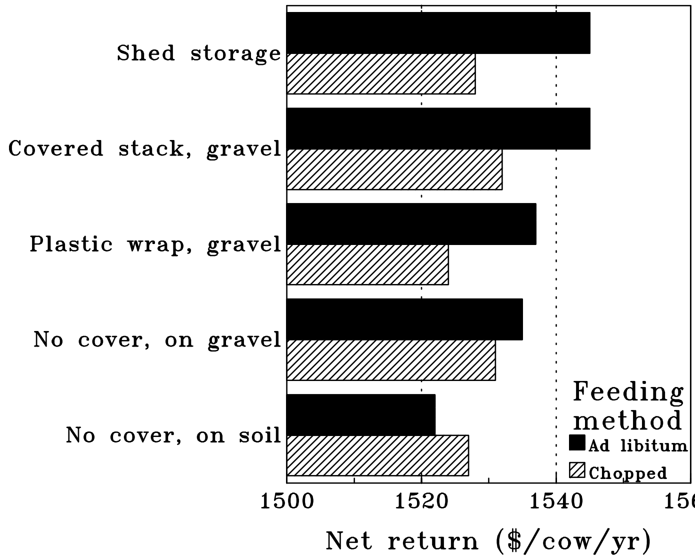

Figure 2. Effects of round bale storage and feeding methods on the net return over feed costs when small amounts of hay are fed in dairy rations along with alfalfa and corn silages.

fed as a small amount of a total mixed ration (Fig. 2). With this system, annual net return was within $8/cow for all storage systems indicating little benefit for protected storage.

Direct-Cut Silage Systems

The technique of ensiling direct-cut alfalfa has long been of interest to eliminate field wilting losses. Simulation was used to compare the long term performance and economics of conventional wilted silage systems to a direct-cut alfalfa harvest and storage system that used a treatment such as formic acid to enhance preservation (Rotz et al. 1993). Reduced harvest losses with direct-cut silage were largely offset by increased effluent losses from the silo, so little difference was found in the quantity and quality of forage available to the animals. Handling of the wetter material increased machinery, fuel, and labor costs for transport and feeding.

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The economic value of direct-cut silage was found to be very poor. Even with no cost for a preservative treatment of the high-moisture silage, an economic loss was experienced by the producer due to the small difference in system losses and the greater cost of handling and feeding wetter material. The economic analysis was relatively insensitive to changes in most parameters and functions assumed. Thus, development of a system for direct-cut harvest and preservation of alfalfa for anything less than an extremely wet climate appears unfeasible considering known technology.

Grazing Systems

Many dairy farmers are considering the use of grazing to reduce feed costs and improve farm profit. DAFOSYM was used to model the performance and economics of a 60-cow dairy farm in central Pennsylvania and a 100-cow operation in southern Michigan with and without the use of grazing. With the grazing option, intensive rotational grazing of alfalfa supplied a major portion of the forage needs of a high producing Holstein herd. Additional forage was harvested, stored, and fed in a total mixed ration.

The net cost of feeding the herd decreased with grazing through reduced use of conserved forages, corn grain, and soybean meal (Rotz 1996). Because grazing animals spent less time in the barn during the grazing season, less bedding was required with 34% less manure hauled each year. Altogether, these effects provided a 12% reduction in the average feed and manure handling cost. On the Michigan farm, grazing of an 18,000 lb herd reduced the total feed and manure handling cost by $0.83/cwt of milk produced compared to the confined feeding system. At a production level of 20,000 lb/cow, the reduction in the feed and manure cost was slightly less at $0.73/cwt. The net return or profit margin of the farm increased by $146/cow or $58/acre. Thus, grazing of alfalfa is an economical option for dairy farms in the northern US The grazing strategy used and other assumptions of the analysis influence the economic benefit received from grazing.

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Manure and Tillage Systems

Recent work has evaluated manure handling systems and their interaction with tillage and feed production operations. DAFOSYM was expanded to simulate the quantity and nutrient content of manure produced as a function of feed composition and consumption, milk production, and animal growth (Borton et al. 1995). Nutrient losses in manure han-

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dling, storage, and application were subtracted to determine nutrients available for crop growth. Manure systems using long-term storage with spreading, injection, or irrigation have greater direct costs to the farmer than the daily haul system commonly used in the upper Midwest. If long-term storage systems are required to protect the environment, the annual net cost of manure handling (total manure cost minus the value of manure nutrients) will increase up to $65/cow for small (60 cow) and $45/cow for large (250 cow) dairy farms.

Comparisons of three tillage and four manure handling systems on representative dairy farms showed mulch-tillage to be the most economical tillage system (Harrigan et al. 1995). Mulch tillage returned $15 to $25/cow-yr over conventional tillage with a 30% reduction in machinery, fuel, and labor costs. A modified no-till system provided a higher return than conventional tillage, but when compared to mulch-tillage, savings in fuel and labor were offset by higher costs for pesticides. The highest net return among manure handling systems was associated with short-term storage and daily hauling, but this economic advantage diminished if credit was not given for the value of all manure nutrients when spread daily. Long-term manure storage concentrated labor for spreading in the spring and fall. This delayed tillage and planting and increased feed costs as much as $24/cow-yr when manure hauling, tillage, and planting occurred in series. When labor and machinery were available for parallel field operations, manure handling method had little effect on the timeliness of tillage and planting.

A Teaching Tool

A new Windows® version of DAFOSYM was recently released for uses other than research. This version is primarily intended for use as a teaching aid. Students in Bio-Systems Engineering, Agronomy, and Dairy Science can use DAFOSYM to learn more about the complexity of the many interactions that occur within a crop and livestock production system. Students may study the effects of relatively simple changes such as the size of a tractor or other machine. Such a change influences the timing of field operations, fuel and labor requirements, the quality of feeds produced, and milk production as well as the costs of production and farm profit. More complex problems may be studied such as maximizing the profit of a given size farm or optimizing the machinery set or structures used on a farm.

The model can also be used in extension-type workshops. Extension field staff, private consultants, and producers may use the model to study the impacts of various technological changes on farms in their area. With some experience, the model may be used to assist with strategic planning. The model can provide useful information on the selection of equipment and structures or in planning for farm expansion.

Obtaining the Model

DAFOSYM for Windows® is available from the home page of the US Dairy Forage Research Center (http://www.dfrc.wisc.edu). The program will operate on any computer that uses Microsoft Windows® version 3.1 or Windows® 95. It functions best on computers using 486 DX or Pentium processors with at least 4 MB of RAM. About 5 MB of fixed disk space is required to store the program and its associated data files.

To obtain a copy of the program, the home page must be accessed through the internet at the address given. From the introductory page, the category of software and databases must be selected. Complete instructions for downloading and setting up the program are provided. The name and address of those requesting the program are requested for our records. A file (DAFOSYM.EXE) is downloaded into a temporary directory on the requester’s computer. By typing the name of this self extracting file, all program and data files are arranged for installation in Windows®. The installation is completed by executing a Windows® based program called SETUP. The setup procedure creates a DAFOSYM window with an icon to call the program. All program and associated data files are expanded and stored in a permanent directory for use.

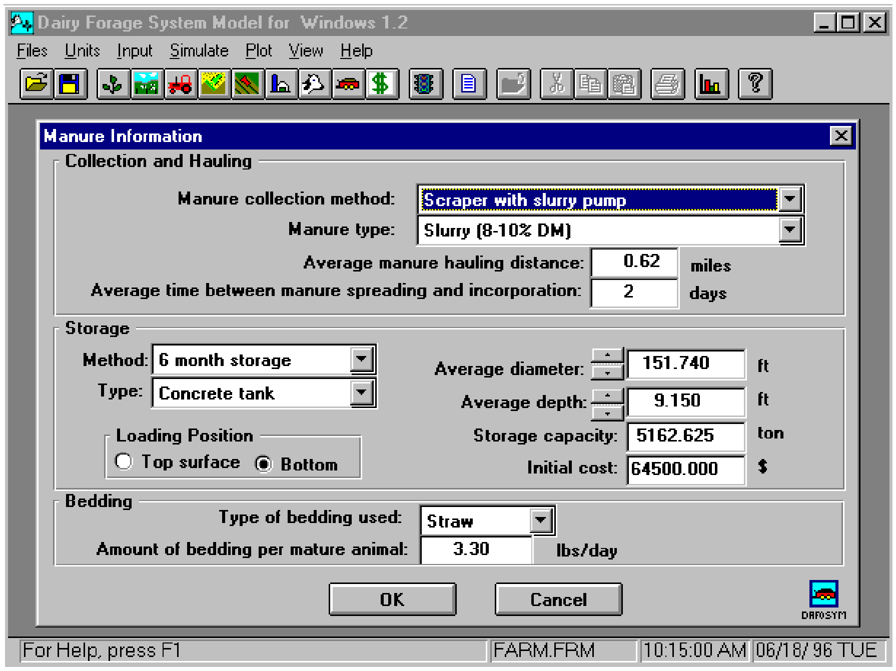

Figure 3. Primary window of DAFOSYM illustrating the icons and menus used to view and modify farm parameters.

Using the Model

As in many Windows®-based programs, the DAFOSYM window opens to display a series of menu options and icons that are used to direct the user through major model functions (Fig. 3). Menus are used to view or modify model parameters. Files supplied with the model provide default values for all parameters of example farms. Parameters are changed by reentering values in an entry box, selecting the appropriate option from a list box, or setting the desired value through a scroll box. Either metric or English units of measurement can be used. A Windows®-type help system assists the user in preparing a simulation and interpreting the results. Help can be obtained in any part of the program by pressing the F1 key. A description of the information required or the output received is provided. The help system provides internal documentation on the use of the model so that a user guide is not required.

Input information is supplied to the program through three data files: farm, machinery, and weather parameter files. The farm parameter file contains data that describe the farm. These parameters include crop areas, soil type, equipment and structures used, number of animals of various ages, harvest and manure handling strategies, and prices for various farm inputs and outputs. The machinery parameter file includes parameters for all machines available for use on a simulated farm. These parameters include machine size, initial cost, operating parameters, and repair factors. Farm and machinery parameters are quickly and conveniently modified through the menus in the user interface. Any number of files can be created to store parameters for different farms and/or machinery sets for later use in other simulations. The weather data file contains daily weather for many years at a particular location. Weather files for about twenty locations are available with the model.

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DAFOSYM creates output in four separate files. Following a simulation, the files requested appear in overlaying windows within the primary DAFOSYM window where they can be selected and viewed. The four output files are the summary output, the full report, optional output, and parameter tables. The summary output provides several tables that summarize the average performance, costs, and returns over the number of years simulated. These values include crop yields, feeds produced, feeds bought and sold, manure produced, a breakdown of feed production, manure handling and livestock expenses, and the net return or profitability of the farm. The more extensive full report includes these values and more. In the full report, values are given for each year of the simulation as well as the mean and variance over the simulated years.

Optional output is available for a closer look at how components of the full simulation are functioning. Optional output tables include daily values of crop growth and development, a summary of the suitable days for field work each month, daily summaries of field operations, a breakdown of how animals are fed, and annual summaries of machine, fuel, and labor use. Optional output is best used to verify or observe some of the more intricate details of a simulation. This output can become very lengthy and as such is only available when requested. In order to obtain a file of manageable

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size, simulation of only a few years is recommended for the daily or monthly output options. Parameter tables can be requested. These tables summarize the input parameters specified for a given simulation.

Several aspects of the model output can also be plotted. These include the pre-harvest and post-harvest crop yields, total feed and manure costs, net return for the farm, and the whole farm balance of the three major crop nutrients. Annual values of these output numbers are ranked from smallest to largest and plotted as a cumulative probability distribution. These plots can be viewed on the monitor and printed on a compatible printer.

Summary

DAFOSYM is a simulation model of the dairy forage system. The model was written as a research tool for evaluating and comparing alternative technologies for the dairy farm. A simulation over 25 years of weather provides a prediction of the long term performance and economics of a dairy farm system. By simulating more than one system for the same base farm and weather data, performance and economic results can be compared to determine the best system. A Windows® version of the model is now available that provides a teaching aid for use in classrooms and extension workshops. The model illustrates the complexity of the many interactions among components of the dairy farm. By working with the model, the user can learn how changes in one component of the farm impact other components and the overall performance and economics of the farm. For the experienced user, the model may also provide information useful for strategic planning. DAFOSYM is published and distributed by the USDA's Agricultural Research Service. The model is available without charge through the World Wide Web from the home page of the US Dairy Forage Research Center (http://www.dfrc.wisc.edu).

Future Plans

DAFOSYM is an evolving model. Additions and refinements are continually being made to expand the model for new applications. Current work emphasizes the addition of more crop options on the farm. Grass forage crops are being included for both grazing and conserved feeding options. Other crops include small grains for silage and grain production, and soybeans for a farm produced protein supplement. This expanded model will be used to study the effects of cropping and feeding strategies. Simulation will be used to determine farming systems that maintain or improve farm profit while reducing the potential loss of nutrients to the environment.

References

Borton, L.R., C.A. Rotz, H.L. Person, T.M. Harrigan, and W.G. Bickert. 1995. Simulation to evaluate dairy manure systems. Appl. Eng. Agric. 11(2):301-310.

Buckmaster, D.R., C.A. Rotz, and D.R. Mertens. 1989a. A model of alfalfa hay storage. Trans. ASAE 32(1): 30-36.

Buckmaster, D.R., C.A. Rotz, and R.E. Muck. 1989b. A comprehensive model of forage changes in the silo. Trans. ASAE 32(4):1143-1152.

Harrigan, T.M., C.A. Rotz, and J.R. Black. 1994. A comparison of large round bale storage and feeding systems on dairy farms. Appl. Eng. Agric. 10(4):479-491.

Harrigan, T.M., W.G. Bickert, and C.A. Rotz. 1995. Simulation of dairy manure management and cropping systems. Paper No. 954509. ASAE, St. Joseph, MI.

Rotz, C.A. 1985. Economics of chemically conditioned alfalfa on Michigan dairy farms. Trans. ASAE 28(4): 1024-1030.

Rotz, C.A., D.R. Buckmaster, D.R. Mertens, and J.R. Black. 1989. DAFOSYM: a dairy forage system model for evaluating alternatives in forage conservation. J. Dairy Sci. 72:3050-3063.

Rotz, C.A., D.R. Buckmaster, and L.R. Borton. 1992. Economic potential of preserving high-moisture hay. Appl. Eng. Agric. 8(3):315-323.

Rotz, C.A., R.G. Koegel, K.J. Shinners, and R.J. Straub. 1990. Economics of maceration and mat drying of alfalfa on dairy farms. Appl. Eng. Agric. 6(3):248-256.

Rotz, C.A., R.E. Pitt, R.E. Muck, M.S. Allen, and D.R. Buckmaster. 1993. Direct-cut harvest and storage of alfalfa on the dairy farm. Trans. ASAE 36(3):621-628.

Rotz, C.A. 1996. Economics of grazing alfalfa on Michigan dairy farms. p. 72-81. In Proc. 26th National Alfalfa Sym. Certified Alfalfa Seed Council, Inc., Davis, CA 95617-1017.

Savoie, P., L.D. Parsch, C.A. Rotz, R.C. Brook, and J.R. Black. 1985. Simulation of forage harvest and conservation on dairy farms. Agric. Systems 17:117-131.